DOCUMENT RESUME

ED 256 564 SE 045 487

AUTHOR Fields, Steve
TITLE Can Abstract Concepts Be Taught to All Students?
PUB DATE Apr 85
NOTE 28p.; Paper presented at the Annual Meeting of the National Science Teachers Association (Cincinnati, OH, April 18-21, 1985).
PUB TYPE Reports - Descriptive (141) -- Speeches/Conference Papers (150) -- Information Analyses (070)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Aptitude Treatment Interaction; *Cerebral Dominance; Cognitive Ability; *Concept Formation; Concept Teaching; *Field Dependence Independence; Literature Reviews; Science Education; *Science Instruction; Secondary Education; *Secondary School Science; Sex; *Teaching Methods
IDENTIFIERS *Science Education Research

ABSTRACT

A review of the literature was conducted to determine if there are instructional treatments that are effective at fostering the learning (conceptualization) of abstract concepts and what personal and/or cognitive attributes favor conceptualization. Areas addressed include: reporting relative effectiveness of findings (including the reporting of explained variance and acceptable levels of explained variance); studies of concept achievement (including studies on the use of concrete exemplars and laboratory/inquiry strategies); cognitive learning style (field dependence/independence); cerebral hemisphericity (preference for right or left brain functioning); cognitive ability level; and gender. The fundamental conclusions drawn are that: (1) there are no consistent methods for the teaching of abstract science concepts; (2) most studies have ignored the individual differences of the learners; (3) aptitude-treatment-interactions do exist for most, if not all, instructional strategies; and (4) certain cognitive attributes of the learner are more indicative of achievement than is the instruction provided. (Author/JN)

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CAN ABSTRACT CONCEPTS BE TAUGHT TO ALL STUDENTS?

by

Steve Fields
Monroe Area High School
Monroe, Georgia

presented at the
annual meeting of the
National Science Teachers Association
Cincinnati, Ohio
April 18-21, 1985

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Abstract

This paper is a synthesis of information obtained from a literature search of studies which attempted to enhance the learning of abstract concepts. In part, the report is a research integration showing the statistical and practical significance of the studies reviewed. Narrative descriptions aid in summarizing the nature of the studies. The conclusions and discussion segment of the paper takes the research base and places it into understandable perspectives for the practicing teacher. The fundamental conclusions are that there are no consistent methods for the teaching of abstract science concepts; that most studies have ignored the individual differences of the learners; aptitude-treatment-interactions do exist for most, if not all, instructional strategies; and that certain cognitive attributes of the learner are more indicative of achievement than the instruction provided.

Can Abstract Concepts be Taught to all Students?

Random sampling is as essential element in experimental designs where achievement is to be measured between contrasting instructional treatments. Yet many researchers, and especially readers of these research reports, assume that there is equality among the subjects (Ss) on all variables pertinent to achievement. More often than not studies fail to control for much more than having equal numbers of the same kind of class (e.g., general biology) involved in each treatment. The researcher then measures improvement usually from pre-and-posttests or an analysis of variance between the treatments. What is actually being assessed is an "across the board" difference in achievement. This could quite possibly be related to any number of variables; some may not even be related to the Ss' cognitive abilities--e.g., time of day.

It was the purpose of this study to review those studies concerned with the teaching of abstract concepts. Studies of instructional treatments used for teaching concrete concepts seemed irrelevant since developmental psychologists generally agree that even students functioning at the concrete operational level, in Piagetian terms, can learn concrete concepts. Yet on the other hand, the learning of abstract (formal) concepts requires cognitive attributes not possessed by concrete operational students (Lawson & Renner, 1975).

Not only did this study examine cognitive ability level as an interceding variable with instructional treatments, but other cognitive attributes as well. Foremost among these were cognitive learning style (field dependence/independence) and cerebral hemisphericity (preference for right or left brain functioning).

Fundamental Question Addressed by the Study

Are there instructional treatments that are effective at fostering the learning (conceptualization) of abstract concepts and what personal/cognitive attributes favor conceptualization?

Reporting Relative Effectiveness

When reviewing the literature for comparative purposes and significance of findings, certain intrinsic problems invariably emerge. Most obvious of these is the "apples and oranges problem." Glass (1977) insisted that it does not make sense to compare different studies unless the variables being tested are similar. Smith (1980) was more specific when she stated that the variables must have the same operational definitions. However, as she pointed out, this is quite unlikely in behavioral studies. Research integration, she states, can serve to rectify this dilemma to a degree. Nothing as in-depth as a complete "meta-analysis," as termed by Glass (1977), was attempted. Rather, a partial narrative integration of research is cited along with a statistical component. This statistical element was utilized to explain

the practical significance of the research findings. "Practical significance" is reported as "explained variance."

Reporting explained variance. Good and Fletcher (1981) suggested that Epsilon-squared and Omega-squared are two convenient methods of reporting explained variance. The values yielded are practically equivalent--omega-squared being somewhat more conservative of an estimate of the two. Burstein, Bank, and Jarvik (1980) reported that these statistics have been known in the psychological literature for some forty years. They have rarely been utilized, even though they can be used to express the strength of any significant finding.

Formulae for computing these two statistics can be found in several sources. Rosenthal (1980) felt that Cohen and Glass give the best summaries. Good and Fletcher (1981) have condensed this information into a format that can easily be applied by educators. Since many research reports do not include an ANOVA table that gives the necessary values needed for most formulae, Good and Fletcher (1981) suggested the following formula (from Lindman, 1974) that can yield an omega-squared from reported F and t scores:

$$\omega^2 = F - 1/F - 1 + (N/I - 1)$$

where I is equal to the number of levels or groups. To compute ω^2 from a t-score, the value is squared to convert it to an F-score (with 1 df for the between variance). Correlation coefficients do not lend themselves to an ω^2. For

this study explained variance is reported as r^2.

At present there appears to be no reasonable way in which to compute an explained variance for nonparametric statistics (Glass, 1977). Thus for this literature review, reported probability values will be viewed as indicators of both statistical and practical significance.

Acceptable levels of explained variance. After explained variance is computed, what is acceptable? This has been debated for years (Brewer, Note 1). Good and Fletcher (1981) recommended the following:

> Researchers in science education report explained variance in addition to the commonly reported tests of significance, since the latter are inadequate as the sole basis for making decisions about the practical importance of factors of interest to science education researchers. (p. 1)

Good (1983) suggested that the reader should decide, from reported values of magnitude of experimental effect, which values are of practical significance.

Studies of Concept Achievement

This study will assess that portion of the Piagetian model that suggests only students at the F-O level--or those approaching this level--will be able to comprehend formal concepts. The following paragraphs will address those studies that are pertinent to this study: studies that tested for the effect of concrete exemplars on the comprehension of formal concepts and studies that utilized inquiry/activities tactics to promote science achievement.

Use of concrete exemplars. Lawson and Renner (1975) reported on a study where student cognitive ability levels were assessed in terms of their ability to comprehend science concepts on achievement tests. This study involved no treatment; instead, it was concerned with the achievement of both concrete and formal science concepts by high school students following a science course. There were three subsamples: 51 biology students, 50 chemistry students, and 33 physics students. Each of these three subject disciplines were assessed with an achievement test for each discipline containing an assortment of questions measuring achievement on concrete and formal concepts; the items were half concrete and half formal. The findings were as follows: cognitive ability level x concrete concepts (F = 10.68, $p < .01$, $\omega^2 = .13$) and cognitive ability level x formal concepts (F = 8.88, $p < .01$, $\omega^2 = .10$).

One approach that has been attempted to assist in the attainment of formal concepts has been the use of models to represent formal concepts. The findings have been mixed, and those showing a difference between the control group and the treatment group have reported findings where the amount of explained variance was quite small. Cantu and Herron (1978) concluded from their study what appears to be the case in several of the studies reported in the literature: "Even though our hypothesis that concrete-operational Ss would benefit from pseudoexamples more than formal-operational Ss was not supported by this analysis, other analyses

of the data suggest that the hypothesis is worth further study" (p. 140). Cantu and Herron's findings were that both C-O and F-O Ss benefitted from the treatment (F = 5.80, $p < .02$, $\omega^2 = .15$). The interaction between the experimental treatment and the cognitive ability level showed a statistical significance of only .41.

Three studies reported treatment effects that were unsuccessful at furthering concept comprehension. Two involved the study of chemistry concepts. Goodstein and Howe (1978_a) found that only F-O Ss were helped by the treatment. The findings were a $\chi^2 = 25.68$, $df = 4$, $p < .001$ for the experimental group and $\chi^2 = 8.94$, $df = 4$, $p < .05$ for the control group. A second study by Goodstein and Howe (1978_b) revealed the same findings. However, the findings here question whether the materials even assisted the F-O students. A third study by Raven and Cole (1978) with community college nursing and therapy students (a human anatomy/physiology class) studied four hypotheses and obtained the following results:

H_1: Formation of concepts, F = 2.21, p = *NS, ω^2 = .009

H_2: Recall of content, F = 1.48, p = NS, ω^2 = .004

H_3: Application of information, F = 2.83, p = NS, ω^2 = .01

H_4: Synthesis of information, F = 6.72, $p < .01$, ω^2 = .04

*NS = a probability value reported that was nonsignificant

Two studies with chemistry students revealed positive findings. Gabel and Sherwood (1980) used a treatment which involved the manipulation of molecular models. The sample size was rather large (N = 220); but the reliability of the achievement tests was poor--of the three measures one had a r_{kk} = .42. The test-retest reliability coefficient was only .51. The following are the results:

H_1: Treatment effectiveness, F = 9.00, p < .003, ω^2 = .03

H_2: Cognitive ability, F = 7.20, p < .001, ω^2 = .02

H_3: Treatment x cognitive ability, F = 1.56, p = NS

The interpretation for the results of the third hypothesis was that the treatment helped Ss at all cognitive ability levels. A second study of college chemistry students was conducted by Talley (1973). The sample consisted of 102 freshmen taking a chemistry course for science majors. The experimental design did not take into account the cognitive ability level of the Ss. A subjective feeling is that the sample consisted of a nonrandom distribution of cognitive abilities since they were all college science majors. The treatment involved the use of 3-dimensional models to represent chemistry concepts. The concepts were formal concepts and the achievement tests measured comprehension and application of the concepts. The following were the results obtained by Talley:

H_1: Total achievement, F = 174.15, p < .0001, ω^2 = .63

H_2: Comprehension, F = 9.34, p < .0027, ω^2 = .08

H_3: Application, $F = 165.12$, $p < .0001$. $\omega^2 = .62$

The results of this pre-posttest design are rather impressive. However, if the sample does consist of individuals who are predominantly T-F or F-O, then the findings support the Piagetian theory.

Herron and Agbebi (1976) conducted a similar study with a sample of 126 using a hypothetical (fictitious) formal concept. Like Talley's study, cognitive ability level was not a variable. The finding was significant for the treatment and the comprehension and application of the fictitious concept: $F = 14.80$, $p < .01$, $\omega^2 = .18$. Again, as cited in previous studies, students who are above the C-O level, and some C-O students, benefit from the treatments. Thus this study does not help to answer the question as to whether C-O students can comprehend and apply formal concepts.

A unique approach to the work that has been accomplished to date was that by Wollman and Lawson (1978). They used concrete-representational materials in the training for formal operational tasks--e.g., Mr. Tall, Mr. Short. The treatment was successful for all tasks. Mann-Whitney U values were given for the tasks, and they ranged from probability levels of $p < .10$ to $p < .001$. The sample consisted of seventh grade mathematics students, but the sample size was only 28.

Dederick and Shrum (Note 2) conducted another study using concrete materials, but again, only those of the highest ability level excelled with the treatment. The treatment

used photomicrographs to represent botanical concepts. Many were concrete concepts. The control group did not use photomicrographs at all, yet the laboratory practical test that was used to assess the treatment effects consisted totally of photomicrographs. It is felt by this researcher that the validity of the testing procedure is questionable since the control group had no previous exposure to analyzing photomicrographs. This study had the largest reported sample (N = 401), and also consisted of high school biology students. The significance level of the treatment with ability level of the Ss was $p < .05$.

Laboratory/inquiry strategies. As was the case with using physical modelling or concrete objects, laboratory/inquiry strategies have revealed comparable results. However, only one study has assessed the cognitive ability level of the Ss, and the interaction of cognitive ability and the treatment. Most have found superior treatment effects, but without knowledge of the cognitive ability level of the Ss, the relevance of these studies is uncertain. As will be shown, of these studies, more than one utilized students of superior ability.

Only one study found negative results. Kulm (1977) studied the effectiveness of a laboratory approach in a mathematics course for college freshmen elementary education majors. The sample consisted of 56 students identified as being C-O and 33 identified as being F-O. The results were significant only for students who were F-O.

Ward and Herron (1980) reported the results of a study involving 256 introductory chemistry students at Purdue University. The Longeot Test was given to assess the cognitive ability levels of the Ss. The treatment utilized the Karplus learning cycle: exploration, concept introduction, and concept application. The achievement tests had very low reliability coefficients--6 out of 7 tests had values of < .45. The general results were reflective of what has been discussed thus far; F-O Ss benefitted most from the treatment. The findings were relatively impressive for cognitive ability and treatment effect alone, but not for the interaction of the two. This study did use both concrete and formal concepts. The findings were the same for both categories. Thus, F-O Ss achieved the concrete concepts better than the C-O Ss. Piagetian theory, as interpreted by Cantu and Herron (1978), suggests that C-O Ss should be able to achieve concrete concepts as well as F-O Ss. In this instance, the converse occurred.

No other studies considered the operational level of the sample; at the same time, the sample sizes were all less than 100. The following studies showed a treatment effect advantage over some strategy not employing activities:

1. Case and Fry (1973): N = 15, low SES, t = 8.40, $p < .001$, $\omega^2 = .82$
2. Post and Brennan (1976): N = 94, the top geometry students in a high school, ability level (F = 37.91, $p < .01$, $\omega^2 = .28$) and ability level x treatment

(F = .09, p = NS, ω^2 = -.0009)

3. Geeslin and Shavelson (1975): N = 34, mathematics students, F = 22.55, p < .01, ω^2 = .39
4. Blake and Nordland (1978): N = 97, freshmen of a teacher education program in Australia, F = 3.60, p < .05, ω^2 = .03

Research Summary of the Teaching of Formal Concepts

The previous section highlighted the relevant studies related to the teaching of concrete and formal concepts. As noted, many of these studies did not account for the Ss' cognitive ability. For those that did, the following is a summary of the treatment effects:

1. Using concrete exemplars: The levels of explained variance were NS and .15 for ability level x treatment; for treatment alone, the levels were .03 and .18; and for ability level and achievement the levels were .02, .10, and .13.
2. Using a laboratory/inquiry approach: Only one value was found for ability level and treatment (ω^2 = -.0009); and for the treatment effect regardless of ability level, the levels were .03, .28, .39, and .82.

The synthesis of findings reflects several things. There have been very few studies that have examined this aspect of the Piagetian model. Of the studies performed, few have considered identifying the Ss' cognitive ability level.

Cognitive Learning Style

> Field dependence/independence describes a generalized approach to one's interaction with the environment, including the analysis to problem solving tasks. An FI, or analytic, person is able to analyze a stimulus distinguishing, retaining, and coordinating relevant items extracted from a distracting background . . . . The FD person is unable to structure a stimulus and to perceive its parts as discrete from the overall field of reference. (Douglass & Kahle, 1978, p. 407)

A number of studies have examined the relationship between learning style and student achievement. The consensus of these findings reveal that FI favors achievement, especially for processes requiring higher levels of thought Krajkovich, 1978; Douglass, 1978; McLeod & Carpenter, 1978; Douglass & Kahle, 1978; Threadgill, 1979; Shymansky & Yore, 1980; Fields, Note 3). Only one study examined the achievement of abstract concepts while controlling for cognitive learning style. Fields (Note 3) found that a verbal instructional treatment was essentially equivalent to a verbal approach augmented with hands-on activities. Where neither treatment was effective, FI favored achievement ($p < .001$).

Douglass and Kahle (1978), in view of their own research and that of others, hypothesized that being FI favors formal operations. They further imply that a likely reason for why so many high school students are at the concrete operational stage is that most of them are FD in terms of their learning style. Shymansky and Yore (1980) and Fields (Note 3) provided comparable evidence that FD is the pervading strategy utilized by high school students.

Conclusions and Discussion

The general finding of this synthesis of research was that there are instructional ploys that may be effective at teaching abstract science concepts. Yet when examined more closely there tends to be an aptitude-treatment interaction (A-T-I). In studies where aptitude variables (in particular, cognitive ability level and cognitive learning style) have been controlled for, certain students were benefitted while other were not. Since most of the studies located in the literature search did not control for aptitude in any fashion, the findings of treatment success must be viewed cautiously. These same studies often reported statistical significance for their null hypotheses, yet the amount of variance explained by their findings was quite small. This, it would seem, is suggestive of other interceding variables that might have been more important than the treatment effects.

Another finding was that there has been a limited amount of study in the teaching of abstract concepts. New studies need to be designed, as well as replications of previous studies. Replicated studies should consider controlling for A-T-I's. Reif (1983) suggested that activities alone may not be adequate for the teaching of abstract concepts. Problem solving skills may predicate a student's conceptualization.

An inference that can be made is that it is quite

probable that several, if not many, variables work concurrently toward the achievement of abstract concepts. Actually, this may not be limited only to the conceptualization of abstract concepts. All learning may be dependent upon a number of variables; and the variables at work may be from a learning strategy particularly unique to each learner. Where this may not seem surprising, the literature has been suggestive as to a number of variables that account for much of the variance when achievement is assessed. In some instances, these variables are beyond the control of the learner--e.g., gender and the time of the day learning occurs.

What does all of this mean for the science teacher? Obviously you cannot control all of these, or maybe any of them. What you can do is to account for them when planning instruction. This will mainly require that you cannot rely on one instructional ploy, even for concepts which are concrete--e.g., recognizing an insect. Where some learners may comprehend what an insect looks like from a verbal description, others can conceptualize this best, or only, from visually seeing an insect (diagrams or the actual creature). Not only will this integration of instructional strategies reach more learners, but it has been demonstrated that it will help all learners by reinforcing the concept (Ornstein, 1972; Samples, 1975_a; Samples, 1975_b; Brandwein & Ornstein, 1977).

The following is a synthesis of the variables found in

the literature search which affect the learning of abstract concepts. Also stated are the probable interactions that occur among them.

Cognitive Ability Level

As has been suggested by the most widely studied paradigm of intellectual development in science instruction (Piagetian Model), only those learners who are formal operational, or approaching this level, can conceptualize abstract (formal) concepts on a regular basis. Learners not possessing formal operations lack the requisite skills to comprehend and apply the concept. Reports by Chiappetta (1976) and Toepfer (1980) were syntheses of studies which examined the cognitive ability levels of students at all levels in schooling. These reports reveal that well over half of all high school students (approximately 85%) are not formal operational. What these data suggest to the practicing teacher is that most of the students are concrete operational, with some in transition to formal operations. With this dilemma conceptualization of abstract concepts is impossible for most students. At present, no instructional strategy or combination of strategies is clearly effective at alleviating this problem.

Cognitive Learning Style

Regardless of concept complexity field independence favors achievement. In the typical heterogeneous high school population, field dependence is the predominant strategy

(Douglass & Kahle, 1978; Shymansky & Yore, 1980). When this variable is examined along with cognitive ability level FD favors concrete operations, while FI favors higher cognitive ability levels. Being FI and of a higher cognitive ability level appears to be a better predictor of achievement than either variable alone (Fields, Note 4). There is no indication from the literature search that any instructional strategy enhances the learning of formal concepts by students of both cognitive learning styles.

Hemisphericity

This research paradigm suggests that most individuals, when faced with unfamiliar problems, will reflexively use one of their cerebral hemispheres as the leading hemisphere in the solution of the problem. The validity of this variable is questionable. Variation in research designs have led to varying results. Still, certain individuals, at least when viewed subjectively, appear to favor either a "right or left brain" approach to learning. The general finding in studies where hemisphericity was used as an independent variable and achievement as the dependent variable has been the following: being left-hemispheric favors achievement and being either left or right hemispheric is more conducive to achievement than being nonhemispheric or not favoring one hemisphere over the other (Ornstein, 1972; Ehrlichman & Weinberger, 1978; Frostig & Maslow, 1979; Friedman & Polson, 1981; Dilling, Wheatley, & Mitchell, Note 5). There

are conflicting reports as to whether hemisphericity correlates well with cognitive ability level or cognitive learning style (Fields, Note 6).

Gender

Though this study did not aim to examine gender as an interceding variable in achieving abstract concepts, it frequently emerged in the literature. The scope of this variable is quite complex when achievement at all levels of difficulty and subject matter was assessed. However, for science and math achievement especially, males are more successful than females (Graybill, 1975; Fairweather, 1976; Restak, 1979; Burstein, Bank, & Jarvik, 1980; Jahoda, 1980; Zakariya, 1981; Jahoda, 1981). Strong correlations apparently exist between gender and cognitive ability level and hemisphericity, yet relationships with cognitive learning style are unclear. In studies that examined gender with cognitive ability level (Dilling et al., 1976; Wheatley, Frankland, Mitchell, & Kraft, 1978; Olson, 1978; Burstein et al., 1980; Gray, 1980; Fields, Note 3) males are more apt to be formal operational, and the converse is generally true for concrete operational subjects at secondary and postsecondary levels. As for hemisphericity, males are more apt to be hemispheric. Among the nonhemispherics, females far out number males (Gur & Gur, 1974; Harris, 1976; Wheatley et al., 1978; Affleck & Joyce, 1979; Gray, 1980; Fields, Note 3).

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